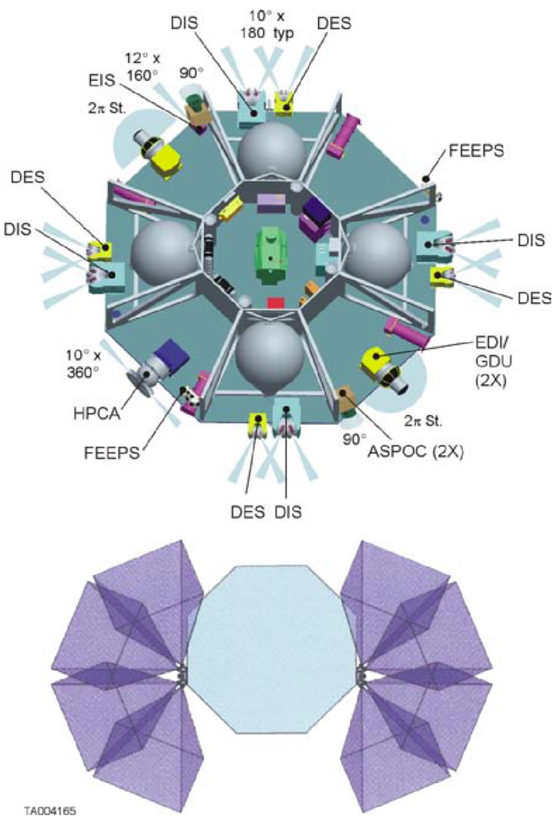

Figure E-15. (revised) *(Top) Instrument fields* ***of view on*** *a strawman MMS spacecraft deck. (Bottom) FEEPS detail* ***(8 of 18 electron FOVs)***.

GDUs require co-alignment to each other and with the magnetometers to ±0.5°.

E.2.2 Hot Plasma Instrumentation

The SMART Hot Plasma instrumentation comprises an array of electrostatic analyzers, collectively called the Fast Plasma Instrument (FPI), and one Hot Plasma Composition Analyzer (HPCA). The FPI provides 3D distributions of total ions and electrons independent of the proposed **3**-rpm spin rate, while the HPCA provides 3D distribution functions for H^+, He^{++}, He^+, and O^+ with half-spin-period (**10**-s) time resolution. The HPCA contains a unique radio-frequency technique that allows the measurement of minor ion species in the presence of the intense proton fluxes encountered in magnetospheric boundary regions.

E.2.2.1 Fast Plasma Instrument (FPI). The FPI comprises eight identical electron sensors (ES), eight identical ion sensors (IS), and an instrument data processing unit (IDPU). The architecture and functional principles are illustrated in **Foldout E-2A**. The ES are improved versions of the Cluster II PEACE analyzers, while the IS have strong heritage in the Geotail and Planet B plasma instruments. The sensors are grouped into pairs whose 10° x 180° fields of view (FOVs) are set 90° apart as shown in **Figure E-15**. The sensor units are distributed around the perimeter of the spacecraft with a 45° spacing of nominal FOVs. The individual sensors are tophat electrostatic analyzers equipped with aperture steering electrodes to cover the full range of azimuths and with position-sensing anodes that image the full range of polar angles. This design provides a full-sky view of the electron and ion velocity distributions at a time cadence that makes the measurements spin independent. FPI performance and resource parameters are listed in **Table E-1**. The energy selection and deflection power supplies can be swept at the limiting practical rate for low-power sweep supplies, approximately 1 kV/ms, so that with an energy analyzer ratio of ~6, the full energy range can be swept in 5 ms. This sweep rate allows for time resolution as high as 5 ms per coarse 3D electron or ion velocity-space distribution. Deflection of the entrance apertures fills in the azimuth distribution to ~10° resolution.

The block diagram of the FPI is shown in **Foldout E-2A**. Individual sensors within a pair unit share all local electronics, including high voltage supplies, except detector biases, which are independently adjustable to compensate for detector gain differences. **Foldout E-2A** presents photographs of the Cluster/PEACE electron sensors and the Nozomi ion sensors, which are the heritage instruments for FPI. Because the FPI sensors have been previously flown in the same context, FPI is for the most part at a TRL of 9. The main innovations for MMS will be: (1) much higher time resolution needed to resolve the diffusion region structure and dynamics; and (2) the addition of electrostatic aperture deflection, which has been flight proven in the SwRI PEPE instrument for DS-1 [*Young et al.*, 2000] and fully developed in the SwRI IES instrument for Rosetta [*Burch et al.*, 1999]. The aperture deflection technology developed by SwRI is being directly inserted into the FPI.

Operations of FPI will be conducted in two modes: Slow Survey and Fast Survey, as described in **Section E.3.1**. The Fast Survey data produce coarse distributions every 333 ms and full distributions every 1.5 s. Burst data, which are captured as a byproduct of the Fast Survey mode, produce coarse distributions every 5 ms and full distributions every 25 ms. The ability of FPI to measure expected electron distribution functions in the reconnection region is demonstrated in **Foldout E-1**.

FPI Accommodation. Contamination control (including clean GN_2 purge during I&T and at the launch site), thermal control (passive conductive), pointing, alignment (±1°), and I&T requirements are typical of this type of instrumentation, which has been flown on numerous prior missions. Mechanical interfaces are accomplished via conventional deck mounting, as shown in **Figure E-15** and **Foldout E-2**. The S/C deck will be oriented orthogonal to the spin axis, so that the top hat symmetry axes lie parallel to the deck plane interface. Electrical and data interfaces are as shown in **Foldout E-2A**.

E.2.2.2 Hot Plasma Composition Analyzer (HPCA). The study of reconnection requires experimental competence in both magnetopause and magnetotail plasma regimes. However, the large particle flux disparities between these regimes shown in **Foldout E-1** poses a significant measurement problem. As also shown in **Foldout E-1**, present-day composition instruments have been unable to measure minor ion species such as O^+ unambiguously at the magnetopause because of high noise levels caused by instrumental spillover effects from the dominant proton fluxes. This effect has precluded any meaningful TOF-based ion composition measurements at energies in the important keV range at the magnetopause—precisely at the reconnection boundary. To overcome this problem, we have developed a new type of plasma composition instrument that can reduce the H^+ flux to extremely low levels while keeping the O^+ flux nearly unaffected.

The optical design of HPCA (shown in **Figure E-16** and **Foldout E-2B**), has strong flight heritage [*Young et al.*, 1989, 1992, 1998]. It consists of an axially-symmetric 360° (top-hat style) toroidal electrostatic analyzer (TESA) coupled with a "straight-through" TOF mass filter that also has flight heritage [*Young et al.*, 1992; *Young*, 1998; *Moore et al.*,1995; *Pollock et al.*, 2000].

Our design addresses the high ion fluxes and large flux dynamic range to be seen during the mission. These we mitigate by combining three techniques: (1) novel application of rf electric fields to part of the inner TESA electrode which preferentially disrupts proton trajectories, rejecting them relative to heavier ions (O^+, etc.) by factors of 100 ~ 1000 (**Figure E-17**); (2) use of high signal capacity MCP detectors to avoid current saturation effects; (3) introduction of four parallel TOF processing microcircuits operating in round-robin fashion to give high event processing rates (~2 MHz random) that avoid electronics saturation.

As illustrated in **Figure E-16** and **Foldout E-2B**, the HPCA directs ions that are transmitted through the TESA through one of sixteen ultra-thin carbon foils and then onto the central region of the circular detector plane, though not crossing or even approaching the center of the MCP. Start electrons emitted from the C-foils are directed onto the periphery of the circular MCP detector, where they initiate a Start timing pulse and are registered in discrete angular sectors (22.5 degrees each) by one of sixteen charge sensitive amplifier/discriminators. The original ion is directed onto the interior region of the MCP detector, where it initiates a Stop timing pulse and is registered in discrete radial sectors (4 mm each) by one of eight charge-sensitive amplifier/discriminators. The radial position sensing provides accurate measure of the flight path from the C-foil to the detector, thereby enabling an accurate speed measurement.

Relationship of Data Products to Scientific Objectives. The HPCA data strategy is described in **Section E.3.1**. No HPCA data are transmitted in the Slow Survey mode. The Fast Survey rate (1.2 kbps) provides 2-minute time resolution for 2 species. Burst mode provides the following data products, all at 1/2-spin cadence:

- H^+, He^{++}, and O^+: 32 Energy x 18 Azimuth x 16 Polar (9216 words each);
- He^+: 16 Energy x 9 Azimuth x 8 Polar (1152 words);
- Background: 16 Energy x 9 Azimuth x 8 Polar (1152 words);
- TOF Spectra: 128 TOF x 4 Azimuth x 4 Polar x 4 Energy (8192 words).

These products allow determination of f(**v**) and its low-order moments for each ion species